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Paper Session II-C - On-Orbit Outfitted Shuttle External Tanks Applied to Lunar Exploration and Industrialization

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ON-ORBIT OUTFITTED SHUTTLE EXTERNAL TANKS APPLIED TO LUNAR EXPLORATION AND INDUSTRIALIZATION

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INTRODUCTION - Exploration of the Moon and development of lunar resources will require delivering habitat facilities to a number of lunar surface locations and include grouping habitats to form colonies plus emplacement of storage facilities for lunar-derived fluids. Liquid Oxygen Tank-Intertank Structure subassemblies derived from the National Space Transportation System (NSTS) External Tank (Figure 1) can be outfitted as Lunar Tank Assemblies (LTA) at the International Space Station Alpha (ISSA) to provide such support facilities. The ISSA would require the addition of an auxiliary truss and a second Space Station Remote Manipulator System (SSRMS); these additions would not compromise the ISSA functionality. On-orbit outfitting would not degrade the structural integrity of the external tanks. These LTA concepts would be capable of autonomous unmanned flight and soft landing at a preselected lunar site. These concepts include habitats and industrial configurations for liquification/storage of oxygen or hydrogen. Previous evaluations of on-orbit outfitting, utilizing the U. S. Space Station Freedom, were performed in support of the NASA Langley Research Center (References 1 and 2). As a result of independent efforts, Bionetics obtained patents for the habitat configuration shown in Figure 2 and for outfitting an external tank as a cryogenic transporter for the lunar-derived isotope Helium-3 (not shown). The current study describes concepts for LTA outfitting at the ISSA with specific features for habitats and industrial storage configurations. Assessments of transit and lunar surface operations led to the conclusion that on-orbit outfitting of LTA's would be an asset to any lunar program.

ON-ORBIT OUTFITTING, GENERAL CONSIDERATIONS - The NSTS Orbiter can carry an external tank into Earth orbit for rendezvous with the ISSA. Outfitting begins with the Orbiter Remote Manipulator System (RMS) arm grasping the intertank structure. Astronauts performing Extra Vehicular Activity (EVA) safe and vent the two tanks and then disconnect the LTA from the hydrogen tank, allowing the RMS to position the LTA, see Figure 3. An Alternate Transfer Vehicle (ATV) proposed by the European Space Agency maneuvers the LTA to the ISSA for outfitting as indicated by Figure 4. The auxiliary truss added to the ISSA serves as a docking and outfitting site. The auxiliary SSRMS, along with the ISSA SSRMS, handles large components during the outfitting process. After docking the nose end of the LTA with the rotating fixture, the ATV returns to the Orbiter and attaches to the hydrogen tank for removal and placement in a parking orbit or preparation for disposal. The ATV docks with the ISSA for later use. The Orbiter docks with the ISSA and transfers the LTA outfitting items, such as structure, components, consumables, etc., to ordered positions along the auxiliary truss for later installation. External outfitting is performed by astronauts in EVA with the LTA in the as-docked position indicated in Figure 5. Fitting an airlock allows transfer of equipment for internal outfitting. For internal outfitting, the auxiliary ISSA arm moves the LTA into a position which mates the LTA airlock with the pressure mating adaptor on the U. S. Habitat Module such that outfitting operations can proceed in a "shirt-sleeve" environment. Electrical checkout and leak testing complete the outfitting sequence in preparation for propellant loading.

Propulsion systems and propellant loading will utilize the same transportation techniques to be developed for manned lunar exploration. Centaur-type hydrogen-oxygen engines are considered representative for LTA outfitting. Propellants would be loaded into dedicated tanks on Earth and lofted by an unmanned booster into co-orbit with the ISSA. Ten propellant tanks are sized to mount inside the intertank, and 16 are sized to mount on the outside. All tanks would be designed for remote "Plug-in" installation. Unmanned booster capabilities would determine the number of tanks and size mix delivered with each launch; several launches would be required. The preferred transfer location is that used for internal outfitting (Figure 5) where the ATV would transfer tanks to the auxiliary SSRMS for placement on the LTA. If necessary, propellant tank transfer could be performed with the LTA in co-orbiting operations.

ON-ORBIT OUTFITTING OF HABITATS - The LTA can be outfitted into configurations capable of supporting all phases of lunar exploration and resource development; Figure 2 shows a habitat which can support a 12-person crew continuously with a 70-day resupply cycle. Such a configuration is considered a practical upper limit for mass delivered to the lunar surface. External outfitting installs the micrometeoroid shield, propulsion system, airlock and elements from thermal control, life support, power, etc., totaling approximately 11,000 kg. About 10,000 kg of internal equipment are transferred through the airlock. Life support-related components account for up to 70 percent of that mass; consumables are estimated at about 25 percent. For habitat configurations, about 7,000 kg of outfitting mass is considered available for mission tailoring to balance needs for crew size, stay time, and mission-specific equipment.

ON-ORBIT OUTFITTING FOR GAS LIQUIFICATION AND STORAGE - An LTA outfitted for liquification and storage of either oxygen or hydrogen requires a minimum of internal tank operations. External outfitting proceeds in the same manner as for habitats; the difference becomes relocation of components from power, guidance, communication, etc., such that all are outside of the tank. Reference 3 summarizes power requirements and masses for space-configured liquification and reliquification systems. Such values applied to a production of 500 metric tons per year of oxygen, or reliquification of 500 cubic meters of hydrogen, indicate that the motors, compressors, and expanders could be housed within the volume (or dimensions) of the present airlock. Masses for storage facilities appear substantially less than those for habitats. Analyses of fusion-based electrical power generation (Reference 4) suggests that lunar-derived Helium-3 as a fusion fuel component could become economically viable. Storage and transport of Helium-3 is enhanced if it can be kept at cryogenic temperature equilibrium with liquid oxygen or hydrogen. Reference 2 addresses such a transport technique using tanks-within-a-tank modifications. Lunar surface storage could also utilize such a concept. Figure 6 shows how an LTA could be outfitted. Some additional special fixturing would be required to position and place the internal tanks by access through the nose port (Figure 4). Helium access lines to the internal tanks, together with the liquid oxygen or hydrogen lines, would utilize the airlock. An estimate of masses shows this configuration also within the mass limits defined by habitats.

TRANSIT TO THE LUNAR SURFACE - Transit to the lunar surface begins with a final electrical checkout after propellant loading. All flight operations would be automated with a trajectory determined by mission requirements and propulsion system capabilities. Dwell time in low lunar orbit was included in the initial analysis. Delivery to a preselected location stands as the defining requirement. Automated landings would draw from Surveyor or Viking spacecraft experiences; pneumatic struts have also been evaluated for habitat landings on the lunar surface (Reference 5)--air bags appear to provide a parallel technology.

OPERATIONS ON THE LUNAR SURFACE - LTA self-check operations on the lunar surface assure a facility to support specifically planned activities before the operating crew and its equipment leave the Earth. The landed habitat would become operational with deployment of a thermal control radiator and filling the space between the micrometeoroid shield and tank wall with regolith to assure radiation shielding (References 1 and 5). Once emplaced, a habitat is capable of resupply and some degree of reconfiguration such that any number of surface missions could be supported. Lunar characterization can anticipate the need for a number of such stand-alone type habitat facilities. Upon identification of an appropriate site for a colony or a base, LTA units can be sequentially landed with each having a configuration tailored to particular functions, such as living quarters, command center, and laboratories; Figure 7 shows such a concept. In a colony arrangement, radiation and thermal shielding make below-grade interconnecting passages an attractive option; the lower airlock door would then become en access port. Gas storage facilities would be at locations of convenience for mining-concentration-reduction type operations and become permanent installations. As an example from Reference 6, a surface deposit of 15 percent Ilmanite, mined for 20 years to a depth of one meter over a kilometer radius, could produce 500 metric tons of oxygen per year with only a 33 percent total recovery fraction.

CONCLUSIONS - On-orbit outfitting of NSTS External Tank sections can provide operating facility support to all phases of lunar exploration and resource development of volumes and masses that cannot be economically duplicated by other means. Habitats could shorten the lunar characterization phase by allowing a wider range of investigations at each site and utilization. A closely grouped cluster facilitates colonization. Capabilities to store and maintain significant quantities of gasses and fluids enhance industrial operations. Thus, in addition to effective utilization of a heretofore discarded element, on-orbit outfitting of external tank elements must be considered a continuously available asset to any lunar program.

REFERENCES

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4. Wisconsin, University of, Madison (1988), Astrofuel for the 21st Century, College of Engingeering.
5. Hypes, W. D. et al; Concepts for Manned Lunar Habitats, NASA TM 104114, August 1991.
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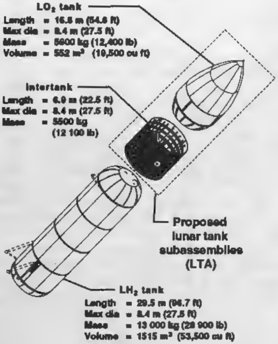

Figure 1. NSTS External Tank Subassemblies

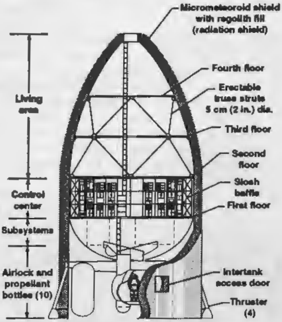

Figure 2. LTA as landed Habitat

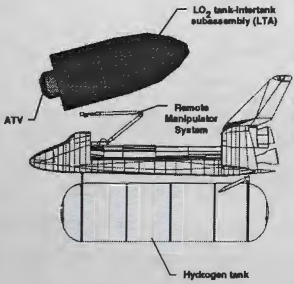

Figure 3. Separated LTA with ATV Attached

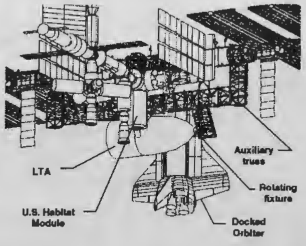

Figure 4. LTA Docked at ISSA Auxiliary Truss

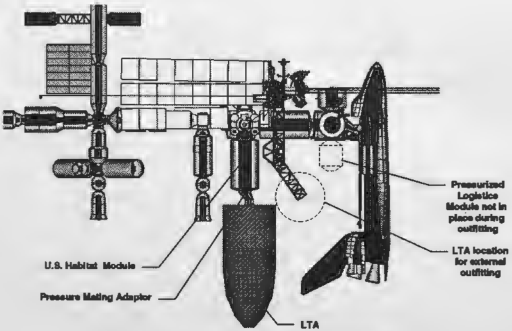

Figure 5. LTA Docked for Internal Outfitting

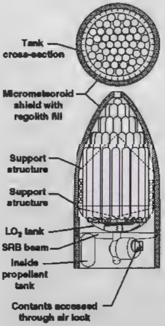

Figure 6. LTA Configuration for Cryogenic Storage of Helium-3

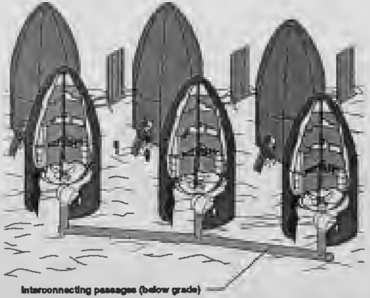

Figure 7. A Concept for a Lunar Colony Using LTA